$1.95

the Transistor Curve Generator

How it works—and how to use it to test NPN and PNP transistors, diodes, zener diodes, FET's, MOSFET's, and other devices—in or out of circuit.

the Transistor Curve Generator

by Charles Caringella

CARINGELLA ELECTRONICS, INC.
UPLAND, CALIFORNIA 91786

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THE TRANSISTOR CURVE GENERATOR

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PREFACE

Transistors and other solid-state devices are now found in all types of equipment, and if you are involved in circuit design or even in servicing such equipment, then the Transistor Curve Generator described in this book can be a most valuable accessory when used with your present oscilloscope. The Model TCG-1 Transistor Curve Generator is a sophisticated, yet easy-to-use test instrument. For the engineer, and even the experimentor, the oscilloscope and Transistor Curve Generator combination form a versatile tool for evaluating transistor and other solid-state device parameters. Service technicians will find the Transistor Curve Generator indispensable and a real time saver when troubleshooting and servicing all types of equipment, since the unit is capable of checking transistors and other solid-state devices in-circuit, as well as out of circuit. For industrial applications, it can be used for incoming inspection of transistors and other solid-state devices. Circuit board assemblies can even be pre-tested on the production line, prior to final installation.

Although this book describes in detail the operating theory and applications for the Model TCG-1 Transistor Curve Generator, as manufactured by Caringella Electronics Inc., the basic operating principles are similar to most other curve generators (may also be called curve tracers) found on the market today. These basic principles also apply to the more complex laboratory-type curve tracer oscilloscopes.

June 1972 Charles Caringella

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CHAPTER 1

SPECIFICATIONS AND FUNCTIONS

The Transistor Curve Generator, when used with an ordinary oscilloscope, will display the dynamic characteristics of both PNP and NPN transistors, FET's, MOSFET's, diodes, zener diodes, tunnel diodes, and other devices. Almost any oscilloscope can be employed, however it must have a vertical sensitivity of at least .1 volt/cm, a horizontal sensitivity of at least 2 volts/cm, and a minimum bandwidth of 100 KHz. This covers most of the general-purpose oscilloscopes on the market today. The Model TCG-1 Transistor Curve Generator includes all the circuits required to generate the base steps and collector sweep voltages for the device under test. An internal fully regulated power supply operates from the 117-volt a.c. power line.

As shown in the photo in Fig. 1, the compact instrument measures only 6" high (without handle) x 4½" wide x 2½" deep. The circuit design is all solid-state, including the panel indicator light! An LED (light-emitting diode) is used on the front panel to indicate when the power is on. Operating the

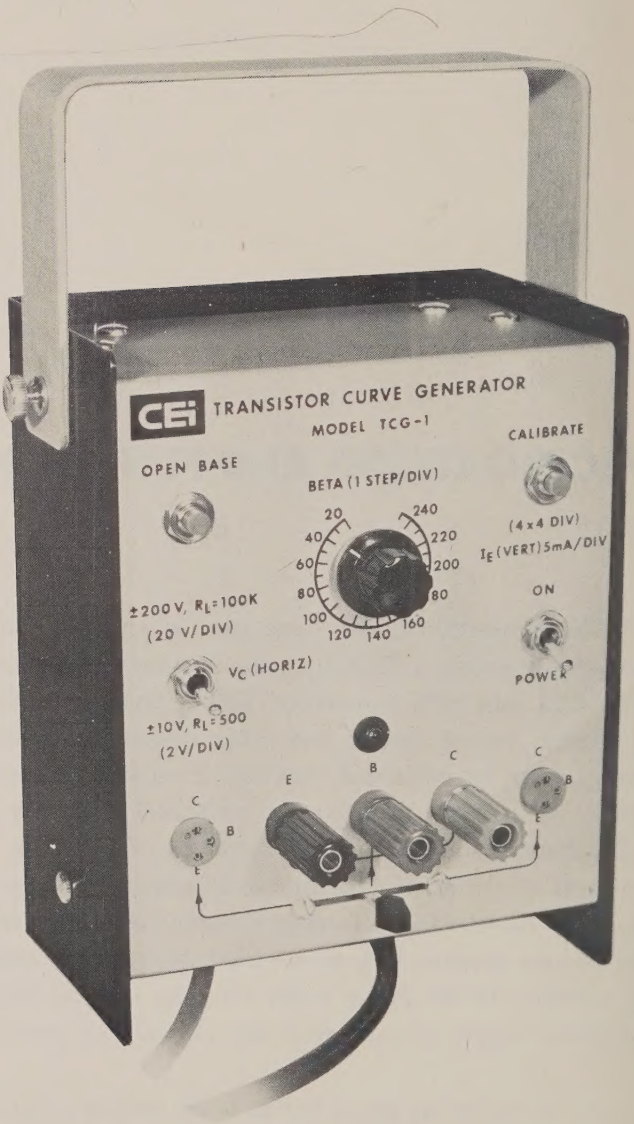

Fig. 1. Front view of the Transistor Curve Generator Model TCG-1.

Transistor Curve Generator is easy and straightforward due to the minimum number of front panel controls. Several unique features are found in the Model TCG-1: 1) Direct readout of transistor gain or "Beta" is provided on the front panel base-drive control. 2) NPN and PNP transistors can be tested consecutively without the need to change controls or switches. 3) Vertical and horizontal channels of the oscilloscope are calibrated simultaneously from the TCG-1 for accurate readings.

The photo in Fig. 1 shows the various controls and switches located on the front panel. Two standard TO-5 transistor test sockets, as well as a set of three color-coded binding posts, are provided on the front panel for testing various semiconductor devices. A three-position lever switch is located directly below the binding posts, and it is used to select either test socket, or the three binding posts. Standard ¾" spacing is provided between the three binding posts, and this will accommodate a variety of semiconductor test fixtures. The binding posts will also accommodate external test leads. Comparing or matching the parameters of two transistors can be accomplished quickly by simply using the two sockets on the front panel and flipping the lever switch back and forth.

A block diagram of the instrument, illustrating the five basic sections of the TCG-1 circuit, is shown in Fig. 2. The power supply section provides regulated +15 volts and -15 volts to the signal generating circuits, as well as a ± 200-volt sine wave for the breakdown test. A ± 12-volt sawtooth waveform is proprovided by the "collector sawtooth generator", which also triggers the pulser circuit. The "pulser" circuit produces a short 17-microsecond current pulse for each cycle of the sawtooth. This pulse advances the base staircase generator one step for each cycle of the sawtooth. The "base staircase generator" then produces 12 steps, from -12 volts to +12 volts.

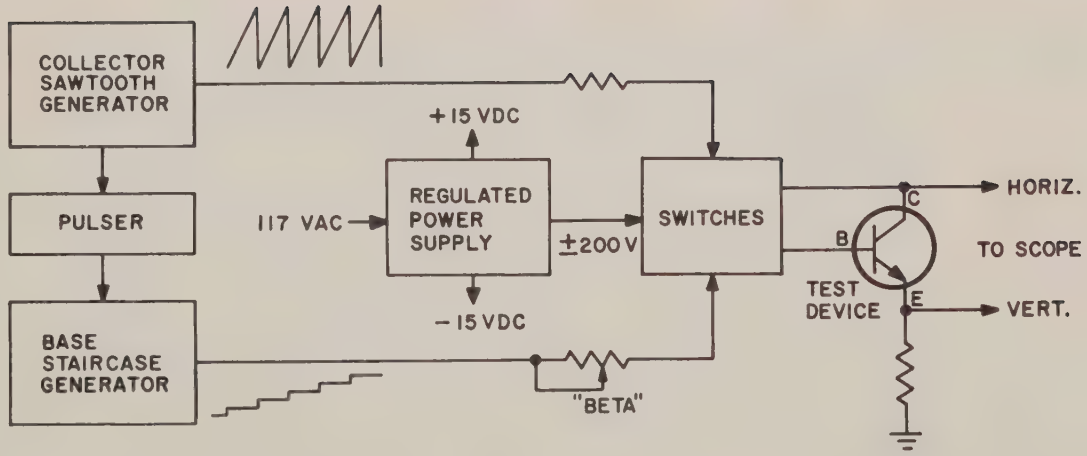

Fig. 2. Block diagram of the Transistor Curve Generator Model TCG-1, illustrating the five basic sections of the circuit.

The complete schematic diagram is shown in Fig. 3 and the Parts List is shown in Fig. 4. What would normally be a rather complex design has been greatly simplified by using high-gain silicon Darlington-amplifier transistors, silicon programmable unijunction transistors, silicon PNP transistors, and a ± 15-volt integrated circuit regulator, in the Transistor Curve Generator circuit. Operation of the instrument consists of three modes: 1) normal mode, 2) breakdown mode, and 3) calibrate.

NORMAL MODE

The "V_C" switch, S2, is located on the front panel of the Model TCG-1, and must be in the ± 10-volt position for "normal mode" operation. In the schematic diagram in Fig. 3, switch "V_C" is shown in the "normal mode" position.

Base current to the device under test is delivered from a staircase of 2-volt steps from -12 volts to + 12 volts through the "Beta" potentiometer, R22, which is also located on the front panel. R22 determines the base current per step.

Collector voltage is supplied from the sawtooth generator through a fixed load impedance of 500 ohms. Collector voltage is delivered to the horizontal amplifier of the oscilloscope and displayed as the horizontal axis of the characteristic curves.

Emitter current through the device under test is displayed on the vertical axis of the oscilloscope by sampling the current through a resistor network consisting of R29, R30, and R31. The resulting voltage waveform is fed to the oscilloscope's vertical amplifier. Since emitter current is equal to the sum of base current and collector current, and since base current is small compared to collector current (by a factor of the current gain,

or "Beta") the display is a good approximation of the usual collector characteristics of a transistor, namely, collector current versus collector voltage.

Collector voltage to the device under test is swept from -12 volts to +12 volts during each step of the base current staircase.

BREAKDOWN MODE

The "V_C" switch, S2, which is located on the front panel of the Model TCG-1, must be in the ± 200-volt position for the "breakdown" test.

In this mode, a ± 200-volt sine wave is applied to the collector of the test transistor through a source resistance of 100K, which is R24 in the circuit. This high source resistance limits the test current to a maximum of 2 milliamperes, to prevent damage to the device under test. Since the sole purpose of this test is to determine the collector breakdown voltage, the base drive is disconnected. In order to display both open-base breakdown (BV_{CEO}) and the shorted-base breakdown(BV_{CES}), a pushbutton switch is provided to open the base or short it to the emitter, as desired. Resistors R27 and R28 sample the applied collector voltage and reduce it by a factor of 10 for compatibility with the sensitivity of the horizontal amplifier of the oscilloscope. A horizontal sensitivity of 2 volts/division will then display 20 volts/division from the device under test. Vertical deflection in the display is again derived from the emitter current resistor network, R29, R30, and R31.

Note that in the case of "base shorted" (pushbutton not depressed) one polarity of the sine wave displays BV_{CES}, while the other half-cycle produces forward bias on the collector-base

junction. In the case of "base open" (pushbutton depressed) one polarity of the sine wave produces BV_{CEO}, while the other half-cycle forward biases the collector-base junction and displays this diode drop in series with BV_{EBO}, the breakdown voltage of the emitter-base junction, another parameter of interest.

CALIBRATE MODE

The "V_C" switch, S2, which is located on the front panel of the Model TCG-1, must be in the ± 10-volt position for the "calibrate" mode.

The system is calibrated by simply depressing the "Calibrate" pushbutton switch, S4. For proper calibration, all test transistors must be removed from the test sockets and binding post connections. In the calibrate mode, the sawtooth waveform is applied simultaneously to the oscilloscope's vertical and horizontal amplifiers, thereby producing a diagonal line display. The sawtooth applied to the vertical channel swings from -0.2 volts to +0.2 volts, while the sawtooth applied to the horizontal channel swings from -4 volts to +4 volts. By adjusting the oscilloscope's sensitivity controls such that the diagonal line is displayed across a 4 x 4 division grid, the oscilloscope will then read 2 volts/division horizontally and 0.1 volts/division (corresponding to 5 milliamperes/division) vertically.

CHAPTER 2

CIRCUIT DESCRIPTION

The complete schematic diagram for the Model TCG-1 Transistor Curve Generator is shown in Fig. 3, and the Parts List for the Model TCG-1 is shown in Fig. 4. Refer to the schematic diagram in Fig. 3 as you read the following circuit description.

POWER SUPPLY

A rather complex dual-output regulated power supply has been greatly simplified by utilizing a unique new integrated circuit regulator. The integrated circuit, IC1, is actually a dual-polarity tracking regulator designed to provide balanced positive and negative output voltages. A total of 24 active elements (transistors and a temperature-compensated zener diode) are utilized in this unique integrated circuit! The regulator output provides +15 volts and -15 volts for the Curve Generator circuitry.

COLLECTOR SAWTOOTH GENERATOR

The collector sawtooth generator is a simple unijunction sawtooth oscillator utilizing a programmable unijunction transistor, Q4, fed from a constant-current source, Q3. The sawtooth is delivered to the output via a complementary emitter follower composed of Q1 and Q2. These are Darlington-amplifier type transistors and provide high current gain to avoid loading the timing capacitor, C2. The sawtooth oscillator frequency is approximately 550 Hz, which results in a "flicker free" display on the oscilloscope.

PULSER

The sawtooth is fed to the base of Q5, to make it saturate when the sawtooth is negative, and to be non-conducting when the sawtooth is positive. As a result, a square wave is produced at the collector of Q5, with its positive-going edge coincident with the negative-going transition of the sawtooth. The positive transition of the square wave is coupled to the base of Q6 via capacitor C3, and this cuts off Q6 until capacitor C3 charges through R12 to return Q6 to its normal saturated state. While Q6 is saturated, Q7 cannot conduct, and hence no current appears at its collector. During the brief "off" period of Q6, however, the base voltage on Q7 falls and causes it to conduct, with its collector current determined by the adjustment potentiometer, R16, which calibrates the base steps. This current is delivered to the base staircase generator, and its magnitude determines the amplitude of each step in the staircase.

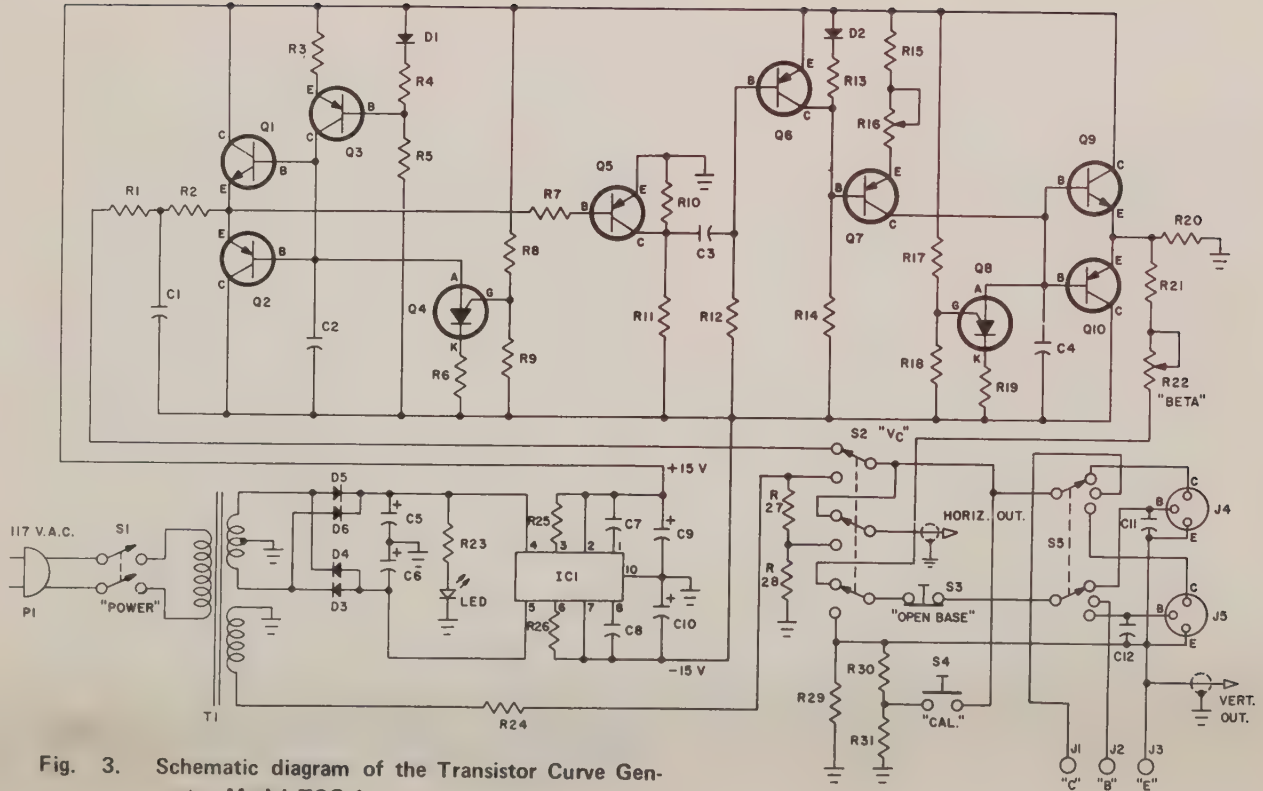

Fig. 3. Schematic diagram of the Transistor Curve Generator Model TCG-1.

PART NUMBER	DESCRIPTION
C1	.1 uf, ceramic capacitor
C2	.01 uf, mylar capacitor
C3	.002 uf, mylar capacitor
C4, C7, C8	.05 uf, mylar capacitor
C5, C6	100 uf, electrolytic capacitor
C9, C10	10 uf, electrolytic capacitor
C11, C12	270 pf, ceramic capacitor
D1, D2, D3, D4, D5, D6	1N914 silicon diode
IC1	SG3501T, integrated circuit
J1	Red binding post
J2	Blue binding post
J3	Black binding post
J4, J5	TO-5 transistor socket
LED	Light-emitting diode, with plastic retainer ring
Q1, Q9	MPS-A14, NPN silicon Darlington-amplifier transistor
Q2, Q10	MPS-A65, PNP silicon Darlington-amplifier transistor
Q3, Q5, Q6, Q7	2N3905, silicon PNP transistor
Q4, Q8	MPU-131, silicon UJT
R1	330-ohm resistor (orange-orange-brown)
R2	150-ohm resistor (brown-green-brown)
R3, R10	4,700-ohm resistor (yellow-violet-red)
R4	1,800-ohm resistor (brown-gray-red)
R5	68,000-ohm resistor (blue-gray-orange)
R6, R19	47-ohm resistor (yellow-violet-black)
R7	33,000-ohm resistor (orange-orange-orange)
R8	1,000-ohm resistor (brown-black-red)
R9	15,000-ohm resistor (brown-green-orange)
R11, R14, R18, R20, R21	10,000-ohm resistor (brown-black-orange)
R12	47,000-ohm resistor (yellow-violet-orange)
R13, R30	390-ohm resistor 5% (orange-white-brown)
R15	82-ohm resistor (gray-red-black)
R16	100-ohm miniature trimmer resistor
R17	820-ohm resistor (gray-red-brown)
R22	100,000-ohm potentiometer
R23	1,500-ohm resistor (brown-green-red)
R24	100,000-ohm resistor 5% (brown-black-yellow)
R25, R26	12-ohm resistor 5% (brown-red-black)
R27	910,000-ohm resistor 5% (white-brown-yellow)
R28	110,000-ohm resistor 5% (brown-brown-yellow)
R29	20-ohm resistor 5% (red-black-black)
R31	620-ohm resistor 5% (blue-red-brown)
S1	D.P.D.T. toggle switch with ¼" lockwasher and two ¼" hex nuts
S2	3.P.D.T. toggle switch with ¼" lockwasher and two ¼" hex nuts
S3, S4	Pushbutton switch with ¼" flat washer and ¼" hex nut
S5	Three-position lever switch
T1	Power transformer

Fig. 4. Parts List of the Transistor Curve Generator Model TCG-1.

BASE STAIRCASE GENERATOR

The base staircase generator is another unijunction circuit similar to the collector sawtooth generator. Because the capacitor C4 is fed from short pulses of current from transistor, Q7, rather than from a constant-current source, its output is a staircase waveform with each "step" held at a fixed voltage by capacitor C4 between current pulses. Each current pulse raises the output voltage one step, until the programmable unijunction transistor, Q8, fires and the staircase begins again. Q9 and Q10 form another complementary emitter follower. R22 is the front-panel "Beta" control.

SWITCHES

S5 is a two-pole three-position lever switch and it simply switches the base and collector signals to either test socket or the binding posts, all of which are located on the front panel. S2, the "V_C" switch, is a three-pole double-throw toggle switch, and it is used to select the "normal" or "breakdown" test mode.

S3 is a normally-closed pushbutton switch and is used for "Open Base" operation. This opens the circuit to the base of the device under test.

The "Calibrate" switch, S4, is a normally-open pushbutton switch, and it connects the output of the collector sweep generator to the emitter circuit of the device under test and also loads down this output. The result is a ±4-volt sawtooth at the horizontal output and a ±0.2-volt sawtooth at the vertical output.

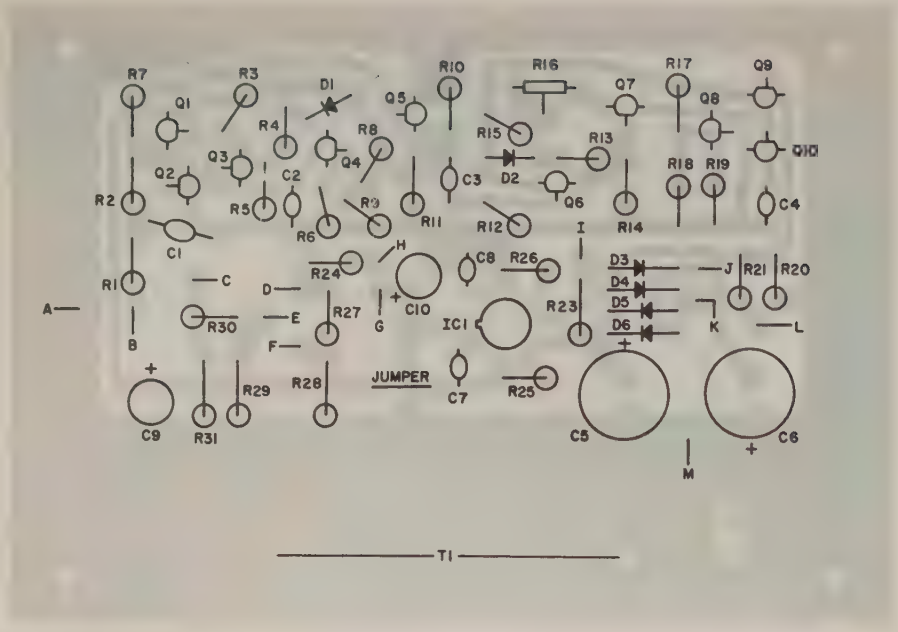

Fig. 5. "X-ray" view of the complete printed circuit board assembly used in the Transistor Curve Generator. Location of all the parts on the "component" side of the board is clearly illustrated.

CHAPTER 3

USING THE TRANSISTOR CURVE GENERATOR

The Transistor Curve Generator should be used with a DC coupled oscilloscope, and the oscilloscope, of course, must have provision for external horizontal input. Also, the oscilloscope must have a vertical sensitivity of at least .1 volt/cm, a horizontal sensitivity of at least 2 volts/cm, and a minimum bandwidth of 100 KHz. An AC coupled oscilloscope may be used, however, the horizontal baseline on the scope will shift whenever a device is tested. When using AC coupled scopes, it will be necessary to re-position the horizontal baseline when testing transistors and other devices.

CALIBRATION

The oscilloscope should be calibrated each time the Transistor Curve Generator is used. Since any oscilloscope will exhibit a certain amount of drift over a period of time, particularly during initial warmup, it is a good idea to check the calibration and trace centering periodically, to insure accurate readings. The "Calibrate" voltages generated by the Model TCG-1 are accurate to ± 10%. In the "Calibrate" mode, the sawtooth waveform generated by the Model TCG-1 is applied simultaneously to the vertical and horizontal amplifiers of the oscilloscope, thereby producing a diagonal line display, as shown in Fig. 6.

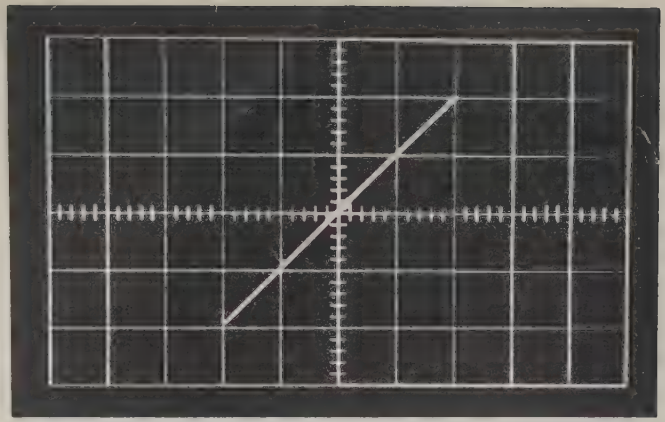

Fig. 6. This diagonal-line oscilloscope display is produced when the "Calibrate" pushbutton on the front panel of the Transistor Curve Generator is pressed. By adjusting the oscilloscope's vertical and horizontal sensitivity controls, so the diagonal line appears across a 4 x 4 division grid, both channels are automatically calibrated.

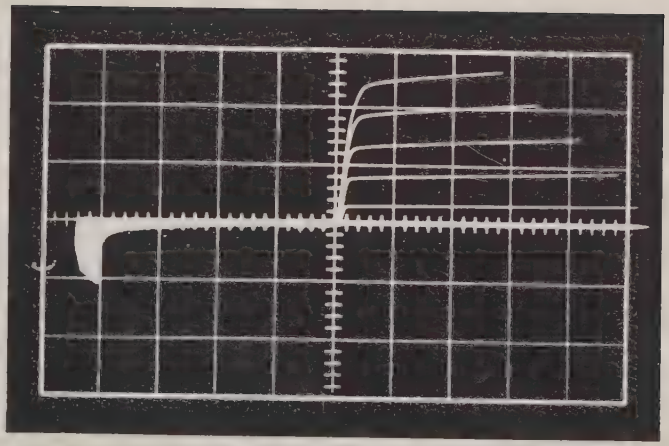

Fig. 7. Collector current versus collector voltage display for a typical NPN silicon transistor (2N3903). Vertical deflection is 5 ma/div and horizontal deflection is 2 volts/div.

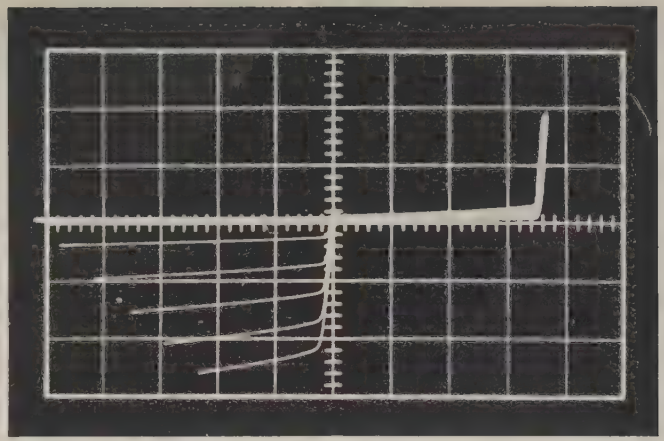

Fig. 8. Collector current versus collector voltage display for a typical PNP silicon transistor (2N3905). Vertical deflection is 5 ma/div and horizontal deflection is 2 volts/div.

For proper calibration, all test transistors must be removed from the test sockets and the binding post connections. The "V_C" switch, S2, which is located on the front panel of the Model TCG-1, must be in the ± 10-volt position, which is the "normal" operating mode. If you use an oscilloscope with triggered sweep, then its internal sweep generator should be disabled, to eliminate the possibility of z-axis modulation of the display. The diagonal line trace, as shown in Fig. 6, will appear on the oscilloscope when the front-panel "Calibrate" pushbutton is pressed. By adjusting the oscilloscope's vertical and horizontal sensitivity controls so the diagonal line is displayed across a 4 x 4 division grid, the oscilloscope is thereby calibrated. The oscilloscope will now read 0.1 volts/division vertically, which corresponds to 5 milliamperes/division. The vertical axis displays the collector current of the transistor under test. Horizontally, the oscilloscope will read 2 volts/division in the "normal" operating mode or 20 volts/division in the "breakdown" mode. The horizontal axis displays the collector voltage of the transistor under test.

Position the diagonal line trace so that it is in the middle of the screen, as shown in Fig. 6. The intersection of the grid at the center of the screen corresponds to DC "zero" for measurement purposes. Note that a bright spot appears in the center of the diagonal line, and it may be used to help center the trace.

TESTING NPN AND PNP TRANSISTORS

Transistors to be tested may be inserted into either test socket, or connected to the binding posts, on the front panel of the Model TCG-1. Two transistors may be compared or matched

quickly by inserting one in each test socket, and then flipping the lever switch back and forth. Each transistor display consists of five curves, which is the collector current versus collector voltage "family of curves." Typical NPN and PNP transistor displays are shown in Fig. 7 and Fig. 8. For this measurement, the "V_C" switch must be in the ± 10-volt position.

The spacing between the curves is varied by turning the front-panel "Beta" control, which actually varies the base drive to the transistor under test. To read "Beta" directly from the front-panel dial, turn the "Beta" control to achieve exactly one-division spacing between any two curves, in the voltage and current region where "Beta" is to be determined. At this point, "Beta" can be read directly from the dial. Refer to Fig. 9 for a typical display in which "Beta" has been determined.

TESTING DIODES

All types of diodes can be tested with the Transistor Curve Generator, including germanium and silicon signal diodes, rectifiers, zener diodes, tunnel diodes, etc. Diodes to be tested are connected between the "E" (emitter) and "C" (collector) binding posts, on the front panel of the Curve Generator. To test diodes, the "V_C" switch, S2, must be in the ± 10-volt position. The forward conduction characteristics of a 1N914 silicon diode is shown in Fig. 10. Diodes may be oriented in either direction between the binding posts, however, in the display in Fig. 10, the diode cathode lead was connected to the emitter binding post.

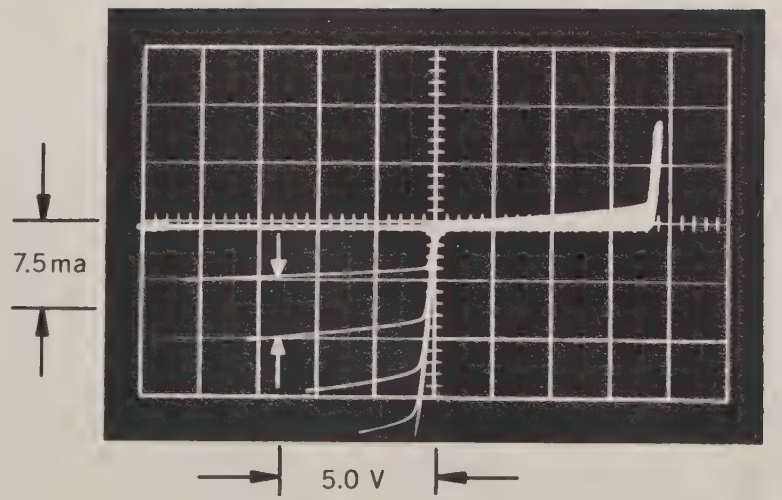

Fig. 9. The front-panel "Beta" control is adjusted to achieve one-division spacing between two curves in the voltage/current region of interest. A 2N3905 PNP transistor was used here, and the "Beta" reading was "110" on the dial, for a collector voltage of 5-volts, and a collector current of 7.5 milliamperes.

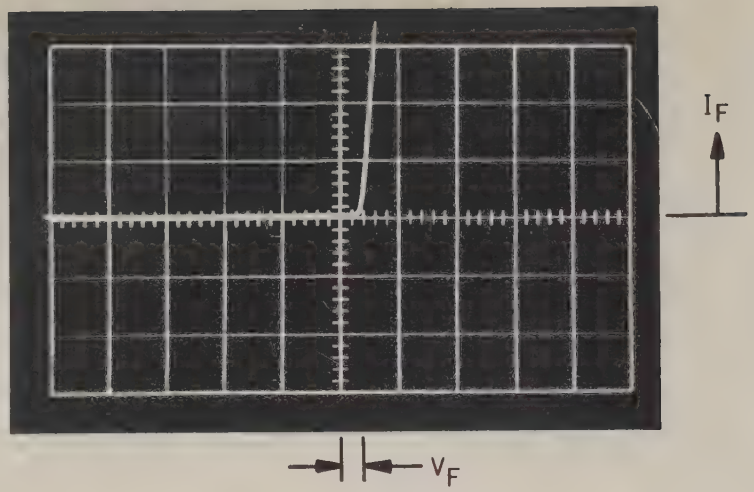

Fig. 10. Forward conduction characteristic of a 1N914 silicon diode. Vertical deflection is 5 ma/div and horizontal deflection is 2 volts/div.

Zener diode voltages can be measured directly as shown in Fig. 11. The zener diode cathode lead was connected to the collector binding post. With the "V_C" switch in the normal ± 10-volt position, zener voltages up to 10-volts can be measured. By changing the "V_C" switch to the ± 200-volt position, higher zener voltages can be measured. In the latter case, the horizontal deflection on the scope is 20 volts/division.

TESTING FET'S

FET's, MOSFET's, and even dual-gate MOSFET's, can be tested with the Transistor Curve Generator. This test, however, will only determine if an FET device is good or bad. For instance, a defective device would not show a "family of curves" on the scope trace. A typical N-channel junction FET is shown in Fig. 12.

FET's may be inserted into either test socket, or may be connected to the binding posts, on the front panel of the Transistor Curve Generator. On FET devices, connect the drain lead to the "C" (collector) test point, connect the gate lead to the "B" (base) test point, and connect the source to the "E" (emitter) test point. When testing FET's, the front panel "V_C" switch, S2, should be in the ± 10-volt position. Dual-gate MOSFET's may be tested by simply connecting the device as instructed above, however, each gate is tested separately.

TRANSISTOR COLLECTOR BREAKDOWN TEST

The sole purpose of this test is to determine the collector breakdown voltage of transistors. Open-base breakdown (BV_{CEO})

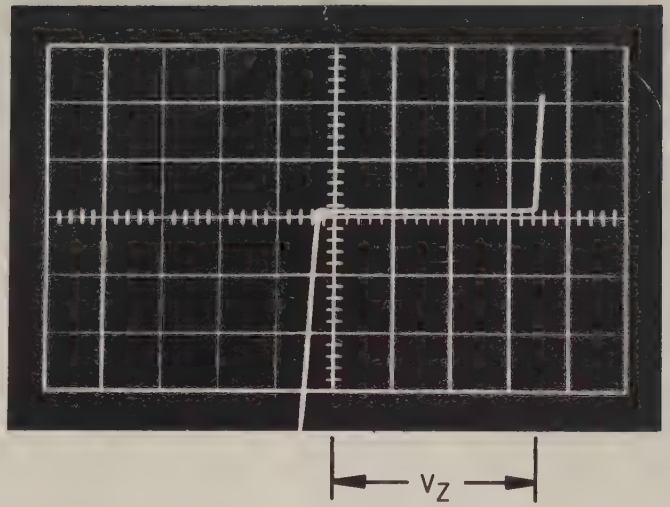

Fig. 11. Typical display for a zener diode. This zener diode is rated at 6.8-volts by the manufacturer. Horizontal deflection is 2 volts/div.

and shorted-base breakdown (BV_{CES}) are determined in this test. To measure transistor breakdown, the front-panel "V_C" switch should be in the ± 200-volt position. In this position, the "V_C" switch disconnects the base drive signal to the transistor under test, and shorts its base to the emitter, for the shorted-base breakdown test. To measure the open-base breakdown voltage, you simply press the "Open Base" pushbutton on the front panel of the Transistor Curve Generator.

CAUTION: HIGH VOLTAGE IS PRESENT BETWEEN THE CASE AND GROUND, WHEN MEASURING BREAKDOWN FOR METAL-CAN TRANSISTORS. The collector is connected to the metal case in most transistors, therefore, high voltage exists between the case and ground in the collector breakdown voltage test. This is true for the Model TCG-1, as well as for other instruments providing the same type of test. In the Model TCG-1, the current during this test is limited to only 2 milliamperes and is not dangerous, however, caution should be exercised.

ACCESSORIES

Three color-coded binding posts are provided on the front panel of the Transistor Curve Generator. Standard ¾" spacing is provided between the binding posts, and this will accommodate a variety of test fixtures and adapters. The photo in Fig. 15 illustrates a typical transistor test socket adapter which is ideal for production testing of transistors and also ideal for incoming inspection. It permits the rapid insertion of transistors for testing purposes. The Adapter shown in Fig. 15 is manufactured by Pomona Electronics, and is known as their Model 1472 Adapter.

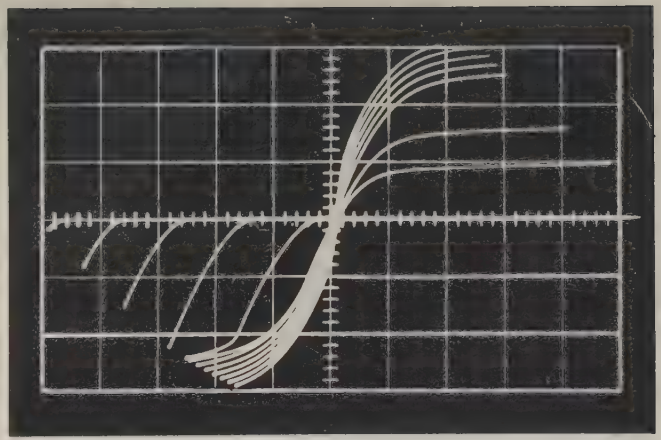

Fig. 12. Typical display for a silicon N-channel junction FET (2N3819).

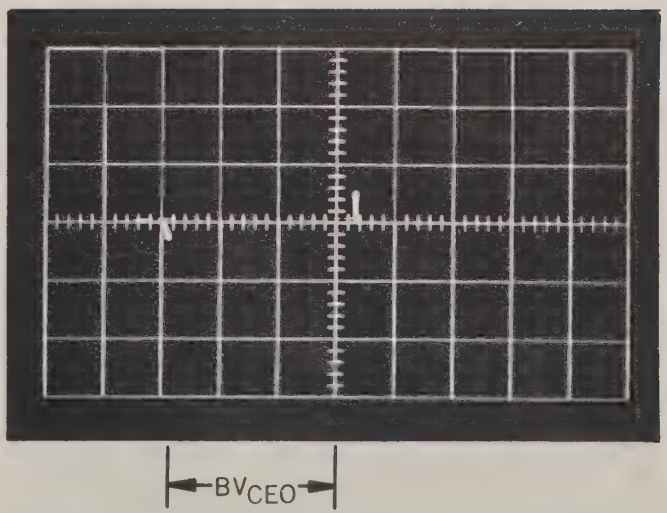

Fig. 13. Open-base collector breakdown voltage for a 2N3905 silicon PNP transistor. Horizontal deflection is 20 volts/div.

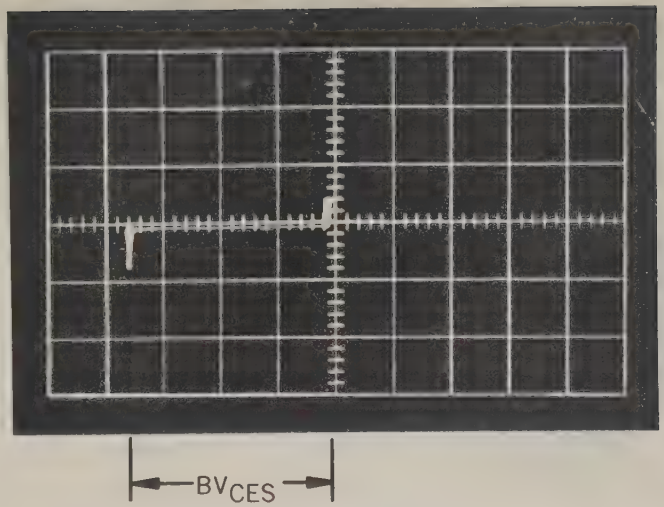

Fig. 14. Shorted-base collector breakdown voltage for a 2N3905 silicon PNP transistor. Horizontal deflection is 20 volts/div.

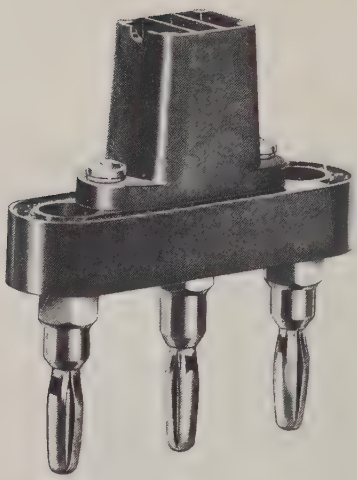

Fig. 15. This transistor test socket adapter is ideal for rapid insertion of transistors.

CHAPTER 4

IN-CIRCUIT TESTING

As an in-circuit tester, the Transistor Curve Generator will quickly spot defective transistors and other solid-state devices. This can be accomplished without the need for additional equipment, such as, signal generators, audio oscillators, etc. The Model TCG-1 is valuable for routine troubleshooting, pre-testing circuit-board assemblies on a production line, etc.

WHEN MAKING IN-CIRCUIT TESTS, POWER TO THE EQUIPMENT UNDER TEST IS TURNED OFF! Typical displays for an in-circuit PNP transistor are shown in Fig. 16 and Fig. 17, which illustrate a 2N3905 transistor in two different circuits. Compare these presentations with Fig. 8, which shows the 2N3905 out-of-circuit. The variations in the displays in Fig. 16 and Fig. 17 are due to the effect of components in the circuit, such as resistors, capacitors, etc. The in-circuit test will only tell if a device is good or bad, since each display will be quite different from that produced for the same device out-of-circuit. However, the presence of a "family of curves," regardless of shape, indicates that the device under test is functioning.

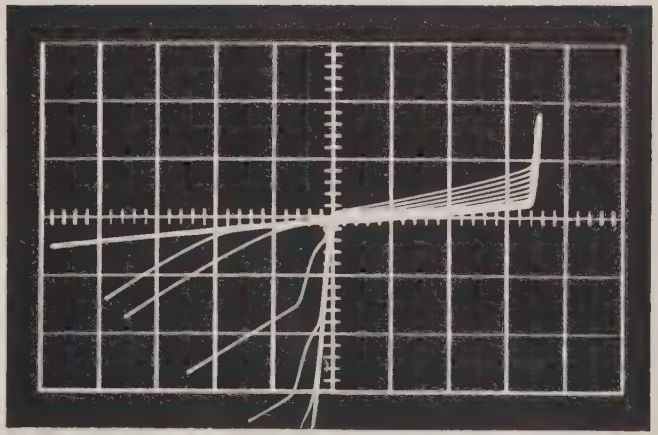

Fig. 16. In-circuit display of a 2N3905 silicon PNP transistor. This is actually the the "signature" of transistor Q3 in the Transistor Curve Generator circuit.

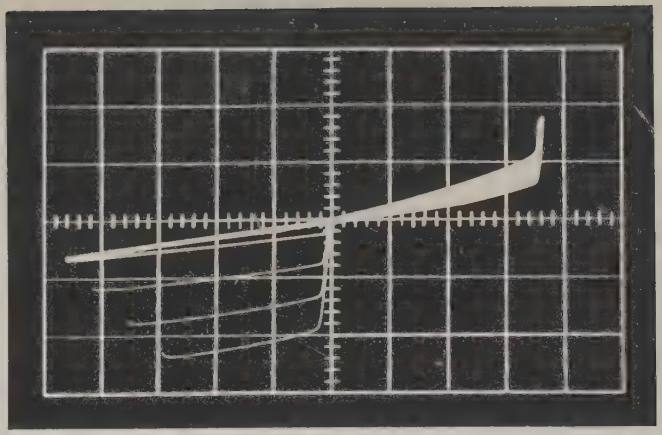

Fig. 17. In-circuit display of a 2N3905 silicon PNP transistor. This is actually the "signature" of transistor Q5 in the Transistor Curve Generator circuit.

Fig. 18. The Polaroid CR-9 oscilloscope camera.

Each stage in a circuit exhibits its own characteristic "signature" pattern, and this fact makes it possible to perform routine troubleshooting in similar circuits by simply comparing these "signature" patterns. The "signatures" in Fig. 16 and Fig. 17 are those of two stages on another Transistor Curve Generator circuit board assembly. Each "signature" would remain the same on all production units of the Transistor Curve Generator.

By employing an oscilloscope camera, a permanent record of each "signature" display can be made for a given piece of equipment, and used for comparison at a later time. An ideal oscilloscope camera is the new low-cost Polaroid CR-9, which is available exclusively from Allied Electronics. A photo of this easy-to-use scope camera is shown in Fig. 18. High-quality photos of scope presentations can be made quickly by using the scope camera and Type 107 Polaroid instant film. All of the oscilloscope dispalys shown in this book were taken with the Polaroid CR-9 scope camera.

CARINGELLA ELECTRONICS, INC.

UPLAND, CALIFORNIA 91786